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EP 0595720 A1

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(54) A phase shifter panel for an electronic scanning antenna

(57) A phase-shifter panel with four phase states, includes conducting wires (F) arranged parallel to the direction of the electric field of an incident wave on a dielectric support (1); each wire bears at least two diodes ( $D_1$ ,  $D_2$ ) mounted in opposition and supplied via control conductors (51, 52, 53) which enable the state of the diodes to be controlled independently of one another. The geometrical and electrical characteristics of the panel are such that to each of the states of the diodes corresponds a given value of phase shift. Conductors (74, 75) parallel to the control conductors are arranged towards the periphery of the support (1).

A stack of such panels forms an active microwave lens for an electronic scanning antenna.

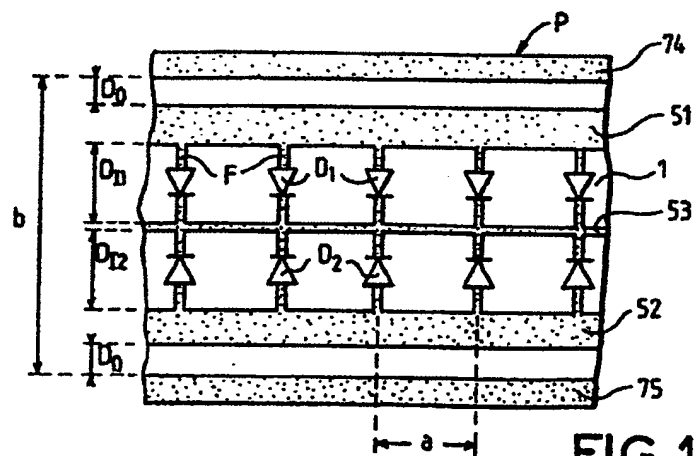


FIG.1

GB 2 280 988 A

1/2

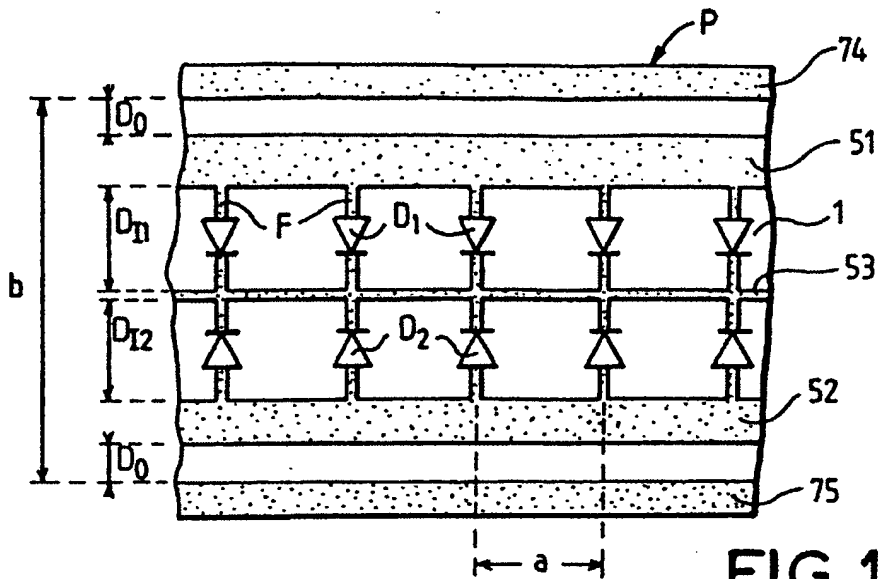


FIG.1

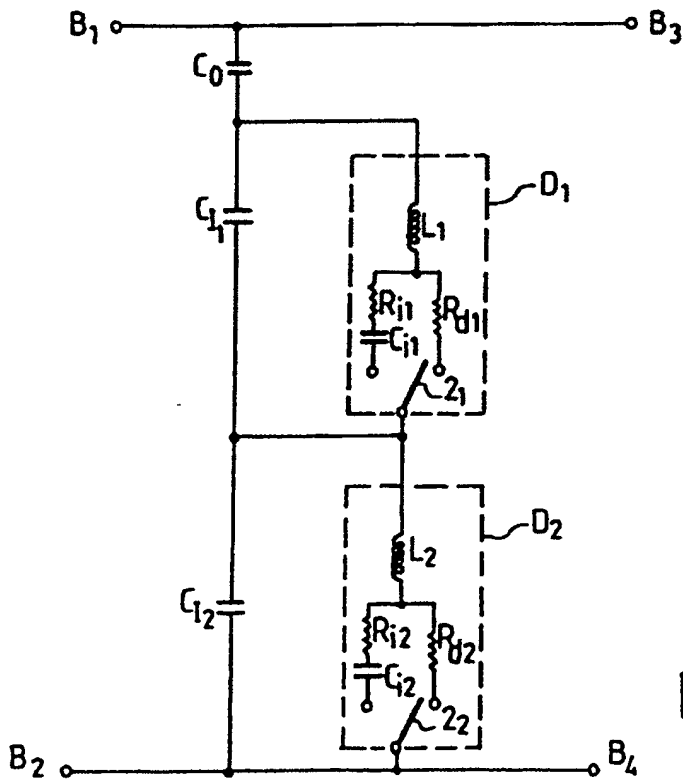


FIG.2

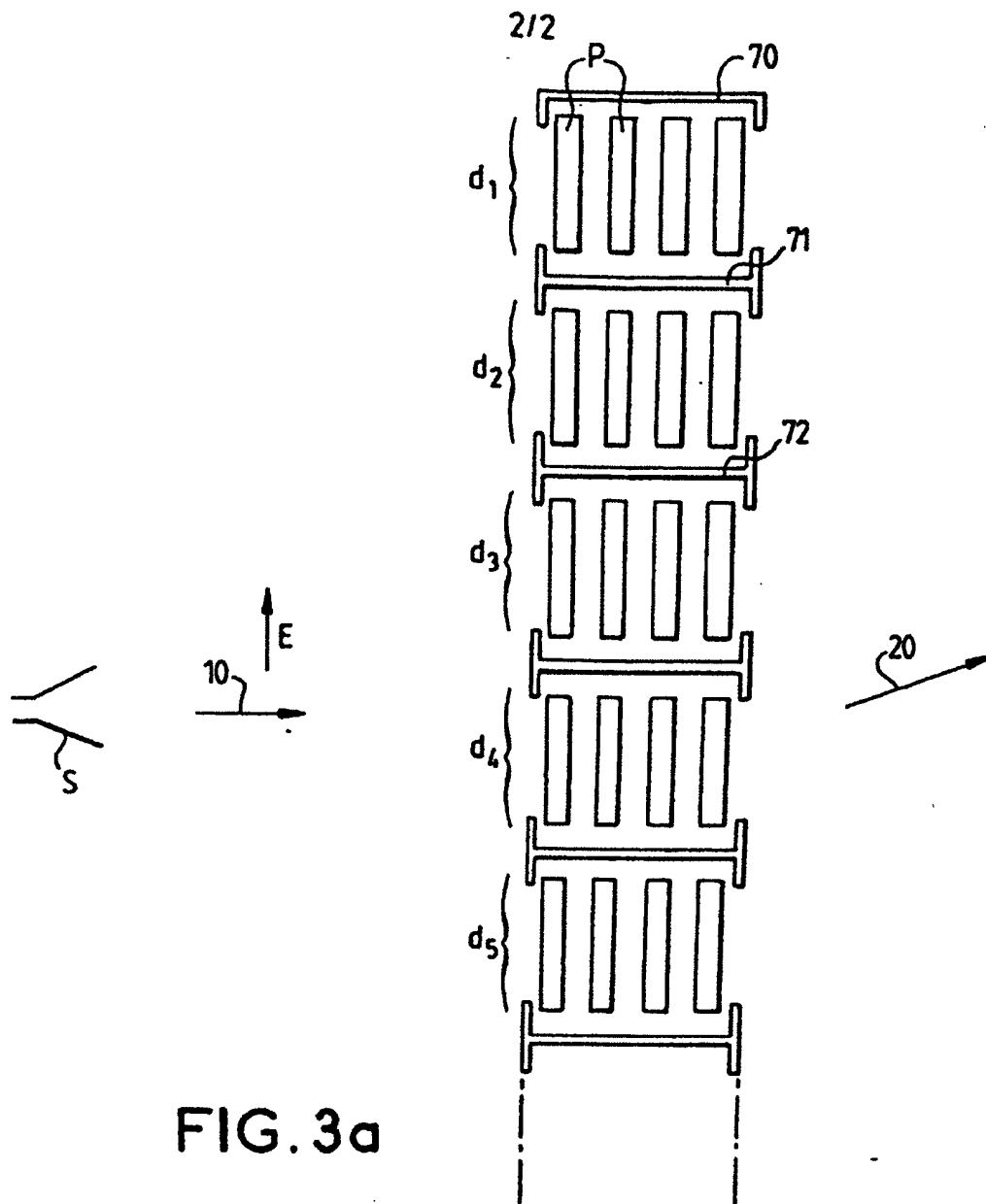


FIG. 3a

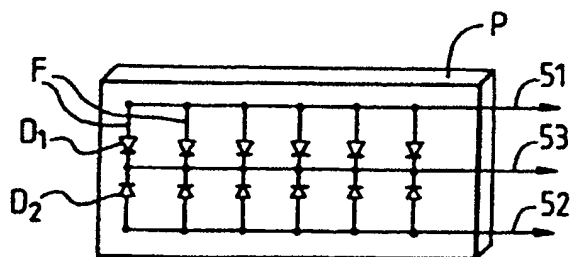


FIG. 3b

"A PHASE SHIFTER PANEL  
AND ITS APPLICATION TO A MICROWAVE LENS  
AND TO AN ELECTRONIC SCANNING ANTENNA "

The present invention relates to a phase-shifter  
5 panel with four phase states, using active semiconductor  
elements. Its subject is also the application of such a  
panel to the construction of a microwave lens and an  
electronic-scanning antenna.

The construction of an electronic-scanning  
10 antenna requires, as is known, components capable of  
applying a controllable phase shift to a microwave. It is  
known for example from French Patent 2,469,808 to use, in  
order to construct an electronic-scanning antenna, a microwave  
lens formed from panels each introducing a phase shift of  
15 the microwave which passes through them. These panels  
include conducting wires bearing diodes, the wires being  
arranged parallel to the direction of the electric field  
of the wave. Control of the passing or blocked state of  
the diodes enables the phase shift imparted to the  
20 incident wave by each of the panels to be made to vary  
between two values and, consequently, electronic scanning  
to be obtained.

However, such an antenna requires that the larger  
the desired number of distinct values of phase shift, the  
25 larger the number of phase-shifter panels, arranged in  
the path of the wave, with an increase in the losses and  
in the cost in particular, this constituting a limita-  
tion.

The subject of the present invention is a phase-  
30 shifter panel which makes it possible to obtain four  
distinct values of phase shift depending on the command  
applied thereto, and thus making it possible in parti-  
cular to reduce the number of panels required in the  
above application.

35 According to the invention there is provided  
a phase-shifter panel capable of receiving an electro-  
magnetic wave linearly polarized in a given direction;  
the panel includes conducting wires arranged on a

support, the wires each bearing at least two semiconductor elements, diodes for example, and being connected to conductors enabling the state of the diodes to be controlled independently of one another, each of the diodes  
5 being able to be in the passing or blocked state; four possible states are thus obtained, and the geometrical and electrical characteristics of the panel are such that to each of these states corresponds a given value of phase shift.

10 The subject of the invention is also the application of such a panel to the construction of a microwave lens of the type described in the aforesaid patent.

Its subject is also the use of such a lens for the construction of an electronic-scanning antenna.

15 Other subjects, features and results of the invention will emerge from the following description given by way of example and illustrated by the appended drawings which represent:

- Figure 1, a diagram of an embodiment of a panel  
20 according to the invention;

- Figure 2, the equivalent electrical circuit diagram of the panel of the preceding figure;

- Figures 3a and 3b, diagrams illustrating the microwave lens which is the subject of the aforesaid French  
25 patent and its application to the construction of an electronic-scanning antenna.

In these various figures, the same references refer to the same elements.

In Figure 1 is represented a partial view of one  
30 embodiment of a panel according to the invention.

This panel is labelled P overall. It includes a dielectric substrate 1 on which are arranged wires F, substantially parallel to one another and each carrying at least two semiconductor elements with two states, D<sub>1</sub> and D<sub>2</sub>, for example diodes, for example connected in  
35 opposition, for example by their cathode. The supply voltage to the diodes D<sub>1</sub> and D<sub>2</sub> is conveyed by three conductors which are substantially parallel to one another and perpendicular to the wires F, labelled 51, 52

and 53, the conductor 53 being the central conductor. The substrate 4 furthermore includes on its two edges, respectively, two metal conductors labelled 74 and 75, substantially parallel to the conductors 51-53 and arranged at a distance  $D_0$  on either side respectively of the conductors 51 and 52. The conductors 51 and 53 are a length  $D_{11}$  apart and the conductors 53 and 52 a distance  $D_{12}$  apart. The wires F are substantially equidistant, with a spacing  $a$ . The conductors 74 and 75 are a length  $b$  apart.

For the clarity of the figures, the surface of the various conductors, made for example in the form of metallic depositions on the substrate 4, is represented in the figure dotted although not seen in section.

Figure 2 represents the equivalent electrical diagram of the panel of Figure 1, for microwaves.

The microwave, with impedance  $Z = 120.\pi.b/a$  and linearly polarized (electric field vector) parallel to the wires F is received on the terminals  $B_1$  and  $B_2$  and encounters three capacitances  $C_0$ ,  $C_{11}$ ,  $C_{12}$  in series, connected in parallel across the terminals  $B_1$  and  $B_2$ . The capacitance  $C_0$  represents the decoupling capacitance per unit length between the conductors 51 and 52 and the conductors 74 and 75, respectively; the capacitance  $C_{11}$  is the capacitance per unit length between the conductors 51 and 53 and the capacitance  $C_{12}$  the capacitance per unit length between the conductors 53 and 52.

Across the terminals of the capacitance  $C_{11}$  is connected a diode  $D_1$ , also represented by its equivalent diagram. The latter consists of an inductor  $L_1$  in series with:

- either a capacitor  $C_{11}$  in series with a resistor  $R_{11}$ ,

- or a resistor  $R_{01}$ ,

depending on whether the diode  $D_1$  is reverse or forward, this being depicted by a switch  $2_1$ .

Likewise, across the terminals of the capacitor  $C_{12}$  is connected a diode  $D_2$  represented by its equivalent diagram. The latter is analogous to that for the diode

$D_1$ , its components bearing an index 2.

The microwave output voltage is taken between the terminals  $B_3$  and  $B_4$ , the terminals of the three capacitors  $C_0$ ,  $C_{11}$  and  $C_{12}$ .

5 The parameters of the equivalent circuit of the diodes, for example of diode  $D_1$ , are defined as follows:

- the inductance  $L_1$  is given by  $L_1 = L_{D1} \cdot \frac{a^\alpha}{b}$ ,

where:  $L_{D1}$  is the inductance of the diode  $D_1$ , bearing in mind its connection wire ( $F$ ) to the conductors 51-53;  $a$  is the distance between two diodes  $D_1$ ;  $b$  is the distance between the conductors 74 and 75;  $\alpha$  is a coefficient characterizing the interaction between the wires  $F$ ;

- the resistance  $R_{11}$  is the reverse resistance of the diode  $D_1$ , modified by the ratio  $a/b$ ;

15 - the resistance  $R_{d1}$  is the forward resistance of the diode, modified by the same ratio;

- the capacitance  $C_{11}$  is the junction capacitance of the diode, modified by the ratio  $b/a$ .

20 The operation of the panel according to the invention is explained below by considering, in a first step, the behaviour of such a panel in the absence of the diodes  $D_2$  and of the conductor 53, which amounts to deleting the block  $D_2$  as well as the capacitor  $C_{12}$  from the equivalent diagram of Figure 2.

25 When the diodes  $D_1$  are forward biased, the susceptance ( $B_d$ ) of the (altered) circuit of Figure 2, can be written:

$$B_d = Z \cdot C_0 \cdot \omega \cdot \frac{1 - LC_1 \omega^2}{LC_1 \omega^2 + LC_0 \omega^2 - 1}$$

30 where  $\omega$  is the angular frequency corresponding to the central frequency of the operating band of the device.

The parameters of the circuit are chosen so as to have  $B_d \approx 0$ , that is to say that, neglecting its conductance, the circuit is matched or, in other words, that it is transparent to the incident microwave, introducing  
35 neither spurious reflection nor phase shift ( $d\phi_{d1} = 0$ ).

More precisely, we choose:

$$LC_1 \omega^2 = 1$$

which leads to  $B_d \approx 0$ , irrespective in particular of the value of the capacitance  $C_{11}$ .

5 When the diodes are reverse biased, the susceptance of the panel can be written:

$$B_R = Z \cdot C_o \cdot \omega \frac{1 - LC_1 \omega^2 + (C_1 / C_i)}{LC_1 \omega^2 + LC_o \omega^2 - 1 + (C_o + C_1) / C_i}$$

10 With the capacitance  $C_1$  being fixed previously, it appears that the value of the susceptance  $B_R$  can be adjusted as, consequently, can that of the phase shift ( $d\phi_{11}$ ) experienced by the incident microwave, through action on the value of the capacitance  $C_i$ , that is to say through the choice of the diode  $D_1$ .

15 Two values of phase shift are thus obtained:  $d\phi_{11} = 0$  and  $d\phi_{11}$ .

If now, in a second step, the existence of the diodes  $D_2$  and of the intermediate conductor 53 are taken into consideration, it is seen that, by an analogous argument, when the diode  $D_2$  is forward biased, the incident microwave experiences no phase shift ( $d\phi_{22} = 0$ ) whereas when the diodes  $D_2$  are reverse biased, it experiences a given and adjustable phase shift ( $d\phi_{12}$ ).

25 If now the whole of the panel is considered, it is seen that it can impress upon the microwave which passes through it four different values of phase shift, depending on the control (forward or reverse bias) applied to each of the diodes  $D_1$  and  $D_2$ .

Indeed:

30 - when the diodes  $D_1$  and  $D_2$  are forward biased, the phase shift ( $d\phi_1$ ) imparted to the incident wave is zero;

- when the diodes  $D_1$  are forward biased whilst the diodes  $D_2$  are reverse biased, the phase shift introduced ( $d\phi_2$ ) is so by the diodes  $D_2$  alone and is therefore dependent on the value of the capacitance  $C_{12}$ ;



- conversely, when the diodes  $D_1$  are reverse biased whilst the diodes  $D_2$  are forward biased, the phase shift ( $d\phi_1$ ) imparted by the panel is so by the diodes  $D_1$  alone and is therefore dependent on the capacitance  $C_{11}$  of these diodes;

- when, together, the diodes  $D_1$  and  $D_2$  are reverse biased, the phase shift ( $d\phi_1$ ) is due at once to the diodes  $D_1$  and  $D_2$  and is therefore dependent on  $C_{11}$  and  $C_{12}$ .

It should be noted that described above is the case in which the parameters of the circuit are chosen so that the zero (or substantially zero) susceptances are such that they correspond to the diodes biased in the forward direction, but that it is of course possible to choose a symmetric operation in which the parameters are determined so as substantially to zero the susceptance  $B_2$ .

Such a panel can advantageously be used in the construction of a microwave lens of the type described in the aforesaid patent and shown diagrammatically in Figures 3a and 3b:

- Figure 3a is a partial and diagrammatic sectional view in the plane of the electric field  $E$  of the microwave;

- Figure 3b illustrates the structure of a panel such as described earlier.

In Figure 3b is the panel  $P$  bearing the wires  $F$ , each of them bearing a diode  $D_1$  and a diode  $D_2$  which are connected by their cathodes for example, as well as the conductors 51, 52 and 53.

The microwave lens of Figure 3a includes a plurality of panels such as  $P$ , arranged between conducting plates 70, 71, 72, which play the role of the conductors 74 and 75 of Figure 1. Together, the panels  $P$  arranged between two plates 70-72 constitute a phase shifter ( $d_1, d_2, d_3, \dots$ ).

The stack of a plurality of phase shifters constitutes an active microwave lens which, when irradiated by a microwave source  $S$ , makes it possible to form an electronic scanning antenna. The source  $S$  provides an electromagnetic wave whose direction of propagation is

illustrated by an arrow 10 and whose electric field  $E$  is perpendicular to the plates 70, 71, 72... and parallel to the wires  $F$  bearing the diodes.

5 With the panels  $P$  being controlled independently of each other, it appears that the phase shifts which they impart to the wave which passes through them can differ from one panel to another. By juxtaposing a plurality of panels one behind the other in the path of the microwave, it is seen that phase shifts can be  
10 obtained which can range from 0 to 360°, in increments linked to the number of juxtaposed panels. It should be noted that the fact that each of the panels according to the invention is able to impart to the wave which passes through it four different phase shifts makes it possible  
15 to reduce the total number of panels. By stacking a plurality of such phase shifters, it appears that it is possible to effect electronic scanning in a plane parallel to the electric field, as illustrated by an arrow 20 showing the direction of propagation of the  
20 emergent wave.

The description given above of the panel was so of course by way of example and different variants are possible: thus, it is possible to connect to a same wire several diodes such as  $D_1$  in the same sense and/or  
25 several diodes  $D_2$ , also in the same sense; this variant makes it possible to decrease the equivalent capacitance of the setup and, consequently, to increase its passband. Similarly, the diodes  $D_1$  and  $D_2$  have been represented as connected in opposition but they can also be connected in  
30 series, on condition that the control circuits are adapted accordingly. Finally, the conductor 53 can be doubled up, and this may ease the supplying of the diodes  $D_1$  and  $D_2$ .

CLAIMS:

1. A phase shifter panel capable of receiving an electromagnetic wave linearly polarized in a given direction, including a dielectric support and electrically conducting wires substantially parallel to the given direction, and arranged on the support, the wires being connected to conductors for control of the semiconductor elements, substantially normal to the wires; wherein the support furthermore includes two conductors arranged towards the periphery thereof, substantially parallel to the control conductors, and wherein the wires bear at least two semiconductor elements with two states, the control conductors being at least three in number so as to control the state of the semiconductor elements independently of one another, the geometrical and electrical characteristics of the panel being such that to each of the states of the semiconductor elements corresponds a given value of phase shift of the electromagnetic wave which passes through it.
2. A panel according to claim 1, wherein the semiconductor elements are diodes.
3. A panel according to either claim 1 or claim 2, wherein the geometrical and electrical characteristics

of the panel are such that the latter is adapted for one of the states of the semiconductor elements.

4. A microwave lens capable of receiving a microwave,  
5 including a plurality of phase shifters, each of them  
being formed of a plurality of panels according to anyone  
of the preceding claims, arranged substantially parallel  
to one another between conducting plates, in the  
direction of propagation of the microwave, the phase  
10 shifters being stacked normal to the said direction.

5. An electronic scanning antenna, including a lens  
according to claim 4 and a source which is capable of  
emitting an electromagnetic wave linearly polarised in  
15 said direction, the electronic scanning being obtained  
in the plane of said direction by control of the state  
of the semiconductor elements.

6. A phase shifter panel substantially as described  
20 hereinbefore with reference to the accompanying drawing  
and as illustrated in Figures 1 and 2 of those drawings.

7. A microwave lens capable of receiving a microwave  
substantially as described hereinbefore with reference  
25 to and as illustrated in the accompanying drawings.

8. An electronic scanning antenna substantially as

to

described hereinbefore with reference to and as  
illustrated in the accompanying drawings.

**Patents Act 1977**  
**Examiner's report to the Comptroller under Section 17**  
**(The Search report)**

Application number  
GB 9415853.2

- 11 -

**Relevant Technical Fields**

(i) UK Cl (Ed.M) H1Q (QEE, QEX, QFF, QFH, QFJ, QFX)

(ii) Int Cl (Ed.5) H01Q 3/46

Search Examiner  
J E EVANS

Date of completion of Search  
8 NOVEMBER 1994

**Databases (see below)**

(i) UK Patent Office collections of GB, EP, WO and US patent specifications.

(ii)

Documents considered relevant following a search in respect of Claims :-  
1-8

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|--|---|

Category	Identity of document and relevant passages	Relevant to claim(s)
P A	EP 0595726 A1 (THOMSON-CSF) - 4 May 1994 - see abstract	1-8
A	US 4447815 (CHEKROUN) - see Figures 4 and 5	1-8

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